REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
14-10-2011	Final	

4. TITLE AND SUBTITLE	
Test Operations Procedure (TOP) 02-2-812A Infrared Measurements of Wheeled and Tracked Vehicles	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHORS	**5d. PROJECT NUMBER**
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
Commander U.S. Army Aberdeen Test Center ATTN: TEDT-AT-WF 400 Colleran Road, Aberdeen Proving Ground, MD 21005-5001	TOP 02-2-812A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
Range Infrastructure Division (CSTE-TM) US Army Test and Evaluation Command 2202 Aberdeen Boulevard Aberdeen Proving Ground, MD 21005	**11. SPONSOR/MONITOR'S REPORT NUMBER(S)** Same as item 8

12. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution Statement A. Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES
Defense Technical Information Center (DTIC), AD No.:
This TOP supersedes TOP 02-2-812, dated 8 May 1984

14. ABSTRACT
This document describes those elements of thermal signatures measurements of military equipment which should be standardized within the U.S. Army Test and Evaluation Command (ATEC). Thermal signatures encompass many types of testing, for many different purposes, sharing only a common technology-a thermal imager. Nevertheless, Test Officers should build their test procedures around these standardized elements.

15. SUBJECT TERMS
MidWave Infrared Forward Looking Infrared
LongWave Infrared Spectral Radiant Intensity

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**B. ABSTRACT**	**C. THIS PAGE**			
Unclassified	Unclassified	Unclassified	SAR	33	**19b. TELEPHONE NUMBER** *(include area code)*

(This page is intentionally blank.)

US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure (TOP) 02-2-812A 14 October 2011
DTIC AD No.

INFRARED MEASUREMENTS OF WHEELED AND TRACKED VEHICLES

*This TOP supersedes TOP 02-2-812 dated 8 May 1984.

1. SCOPE.

a. This Test Operations Procedure (TOP) describes techniques and instrumentation employed to measure the Midwave-InfraRed (MWIR) and Longwave-InfraRed (LWIR) radiation, over a short distance (less than 100 meters (m)), during development and production tests of military ground vehicles and weapons, and the conditions necessary to conduct these measurements. Graphs and diagrams are presented to indicate typical measurements, but are not intended to represent any particular test results or evaluation.

b. The Forward Looking InfraRed (FLIR) imaging community, in the Military disciplines, has typically described the MWIR as nominally between 3 and 5 micrometers (μm) and the LWIR as that portion of the electromagnetic spectrum lying nominally between 8 and 12 μm. These definitions are not typical of all disciplines using this part of the electromagnetic spectrum. However, these are the definitions used in this document.

c. The objectives of the measurements include the collection of InfraRed (IR) signature data on a fully exercised vehicle under neutral environmental conditions, as well as reference signature measurements on a cold, inactive vehicle. A neutral environment is defined as the absence of adverse weather conditions such as rain, fog, snow, or high winds and dust. The environmental conditions existing during the actual testing must be fully characterized. A diurnal test should collect IR signature data on an inactive vehicle with no internally generated heat, experiencing only the range of solar loading incurred during a characteristic 24-hour period. The measurements should include detailed IR data with sufficient supporting data to fully characterize the IR signature characteristics of the System Under Test (SUT) in a full range of viewing aspects.

2. FACILITIES AND INSTRUMENTATION.

2.1. Facilities.

A primary requirement for the measurement facility is a location which provides for the observation of the SUT from a wide range of depression angles with the full range of target azimuth angles. A track must be provided for the testing, and exercise, of the SUT at representative speeds. The facility should ideally provide sufficient, permanently installed power hookups for the extensive instrumentation required, as well as sufficient safety and security provisions for test conduct. Specific facilities are listed in Appendix A.

a. Turntable. The emplaced turntable should be set into the ground so that its rotating surface is only slightly above ground level and a vehicle can be driven directly onto the platform. An example of this type of setup, using a turntable, is shown in Figure 1. Care must be taken to retain a natural terrain around the platform for the contrast measurements and the target-terrain interaction.

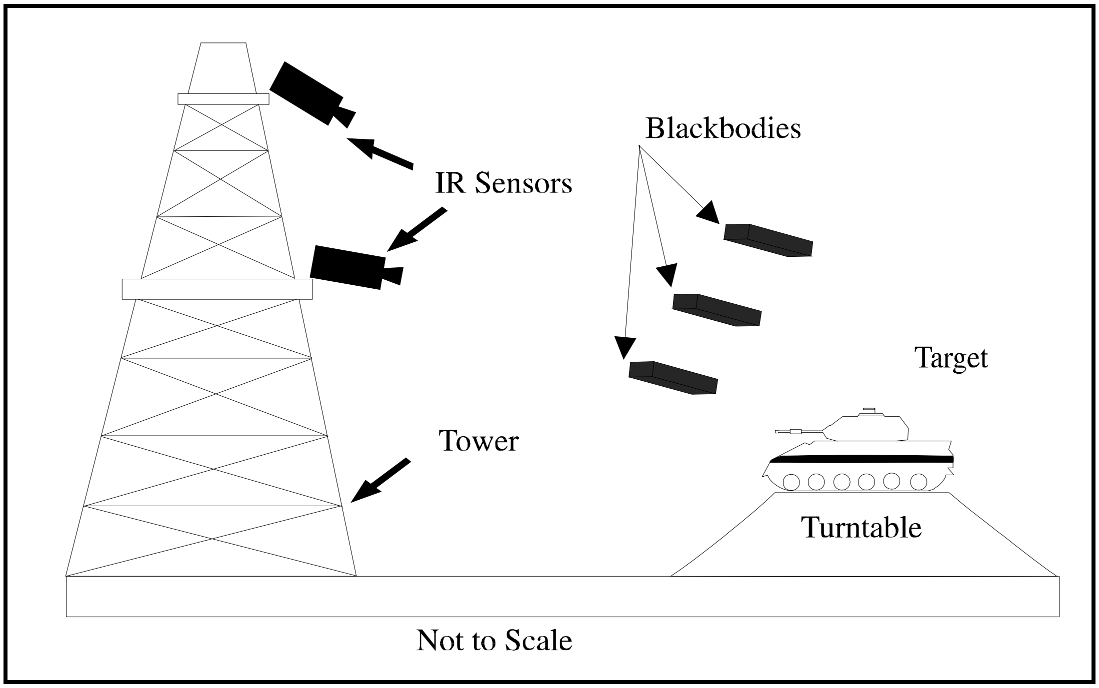

Figure 1. Example of a potential setup with turntable and elevated IR sensors.

b. Test Track. The test track should allow viewing the SUT from various angles. Figure 2 depicts an example of a test track setup. Once again, care must be taken to retain a natural terrain around the track to ensure reliable contrast measurements and the target-terrain interaction.

c. Support Facilities. Ground facilities at the range location ideally include a fixed building, with visual sight onto the range, and instrumentation vans. The fixed building has a number of advantages associated with a static site including permanent facilities power hook-up, instrumentation support, security, and ease of setup. On-site vans provide mobile shelters for a wide range of instrumentation.

d. Additional electronic equipment includes:

(1) Data recorders.

(2) Timing insertion unit (for tagging recorded data with date, International Range Instrumentation Group (IRIG) time, and run logging data).

(3) Digital recording devices with IRIG time.

(4) Global Positioning System (GPS) location unit.

(5) Transient signal digitizers.

(6) Radio communications equipment.

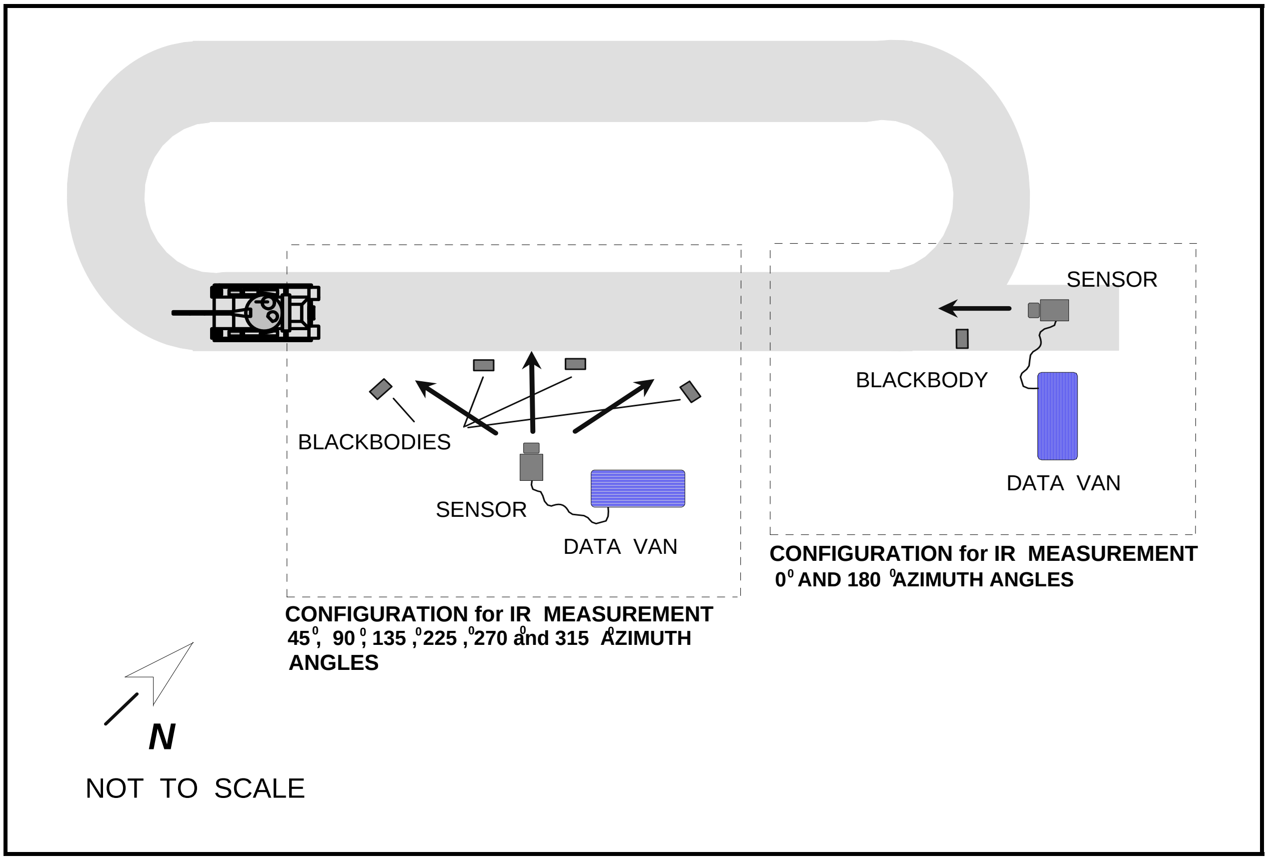

Figure 2. Example of test track and instrumentation setup.

e. The facility should also include an electronic centralized data logging system. Such a logging system makes the scheduling and collecting of field data a more reliable and less tasking process.

f. Whatever the test facility used, target position data are an important adjunct to field testing. Target position is particularly important during moving target tests and can be provided in real time through radio frequency (RF) modems transmitting GPS data or through ranging radar. Alternatively, a manual system based on a laser rangefinder could provide ranging data periodically.

2.2 <u>Instrumentation</u>.

a. Thermal Imagery. Various thermal imagers will be used. They will differ as to exact spectral response, even if they operate nominally in the 3-5 or 8-12 micrometer band pass region. Specialized imagers, such as multispectral, hyperspectral and ultraspectral, differing as to spectral resolution, may also be used. Multispectral, hyperspectral and ultraspectral sensors collect a set of datacubes, each taken in a very narrow band pass, usually a fraction of a

wavelength, over a region several wavelengths wide. Additionally, imagers may be fitted with spectral or polarizing filters.

b. Sensor System Parameters. There are two primary requirements of sensor performance. The first is the detection of scene temperature differences (temperature resolution) of at least 0.1 ºCelsius (C) for characteristic target features (spatial resolution) of importance in the imager Field of View (FOV). This characteristic is reported as the Minimum Resolvable Temperature (MRT) at a target frequency in cycles/milliradian (cy/mrad). The MRT is usually presented as a curve to indicate the total system performance over a range of spatial resolutions. Additional curves could be generated for various background temperatures. The second is the minimum capability of the imager to detect any difference in the temperature from the noise. This characteristic is reported as the Noise Equivalent Temperature Difference (NETD) (or differential temperature) at a specified background temperature. There is one additional characteristic required of all imagers. This is the relative spectral response which is used in the data reduction algorithms. This characteristic is reported as a detector output versus a known input over the wavelength region of interest, and is generally presented as a graph.

c. Multiple Element (Detector) Sensors. If an IR imager with multiple detector elements is employed (e.g., focal plane array), it is important to specify the uniformity of detector response since variations in such response can affect the determination of apparent temperature in different areas of the scene.

d. Other Sensor Characteristics. Other sensor characteristics, such as FOV, Wide Field of View (WFOV), Narrow Field of View (NFOV), Instantaneous Field of View (IFOV) and pixel resolution, do not have absolute requirements since they depend on how the system is used, the display resolution, the distance from the target, and the dimensions of the target areas to be resolved. These should be chosen appropriately for the required measurement. All of the sensor characteristics should be reported for a complete test report. Table 1 presents a list for some of the more important sensor parameters with example (not required) specifications. This list is only intended as a checklist to evaluate for a particular measurement set.

TABLE 1. INSTRUMENTATION PARAMETERS

Devices for Measuring	Permissible Error of Measurement
Spatially resolved apparent temperature in the 3- to 5-µm and 8- to 12-µm spectral bands	±0.1 ºC (relative) and ±0.1 ºC (absolute)
Pyranometer	±2 percent of reading
Spectral resolution	±0.05 µm or ±10 wavenumber (cm^{-1})
Field-of-view (FOV)	±0.1 º

TABLE 1. CONTINUED

Devices for Measuring	Permissible Error of Measurement
MRT	±0.05 ºC/mrad
Blackbodies Type (2)	Extended area sources
Size	±1 centimeter (cm)
Surface stability	±0.1 ºC
Temperature stability	±0.1 ºC
Temperature uniformity	±0.1 ºC over 80 percent of exposed surface area
Temperature settings	±0.1 ºC
IR radiometer	±0.1 ºC
Spectral radiometer measuring equipment	±0.02 radiance
Meteorological Data	See Appendix A
NETD	±0.1 ºC at 300 ºKelvin (K)

e. Blackbody Calibration Sources. Blackbody calibration sources are intended to be placed in the target scene for recording within the collected image. Since these can be set to known temperatures, they provide a means of image calibration. Typically three blackbodies are used. One is set to be slightly hotter than any object in the target scene, one colder than any such element, and a third is set to an intermediate temperature. Depending on how they are used, characteristic requirements of the sources include:

Parameter	Characteristic Values, Precision
Manufacturer	Not applicable
Type and model	Not applicable
Dimensions - overall	35 by 35 cm
Controlled area	30 by 30 cm
Pattern type	Bars, square

Parameter	Characteristic Values, Precision
Temperature range of operation:	
Low Source	Ambient to 100 ºC
High Source	60 to 600 ºC
Precision of Surface Stability	0.1 ºC
Calibration procedures employed	(Direct contact thermocouples or thermistors measurement of temperature or determination by calibrated radiometer)

f. As part of the measurement process, it is necessary to be able to convert the observed image intensity values in the IR sensor into apparent temperatures as represented by the calibrated blackbody sources. With blackbodies at known temperatures bracketing the scene radiance values in the image, it is possible to convert the image intensity of the target elements into apparent temperature values.

g. To this end, absolute radiance values at the measurement location should be verified using a calibrated radiometer containing spectral filters which match the spectral response of the sensor's 3- to 5-μm and 8- to 12-μm wavelength bands. Alternatively a spectral radiometer can be used to determine the radiance as a function of wavelength.

h. Spectral Measurement Instrumentation.

(1) If spectral (non-imaging) data are required, they must be acquired using a spectral radiometer in the 2- to 12-μm wavelength region. There are three primary requirements of radiometer performance. The first is the minimum capability of the system to detect any difference in the temperature from the noise. This characteristic is reported as the NETD at a specified background temperature.

(2) The second is the Noise Equivalent Power Density (NEPD), a measure of a detection system's sensitivity. It is usually defined as the input power level that induces a system signal level having a signal to (system) noise ratio of one. This requires a voltage measurement of the system output as a function of (a variable) input signal.

(3) The third primary requirement is the uniformity of the response over the system's total FOV. The single element detector is not scanning the FOV but encompasses the total FOV. There are variations in the optics, and the detector itself, which will lead to a non-uniform response across the total FOV.

(4) Other radiometer characteristics, such as FOV, do not have absolute requirements since they depend on how this system is used and the distance from the target. These should be chosen appropriately for the required measurement.

(5) All of the radiometer characteristics should be reported for a complete test report. Table 2 presents a list for some of the more important parameters with example (not required) specifications. This list is only intended as a checklist to evaluate for a particular measurement set.

TABLE 2. EXAMPLE OF SPECTRAL RADIOMETER SPECIFICATIONS

CHARACTERISTIC	SPECIFICATION
FOV total	10 x10^{o}
Detector type	Indium-Antimonide
NETD	< 0.15 ºC at 300 ºK
NEPD	2.4 X 10^{-9} W/cm^{2}
System dynamic range	>10^{5}

i. Meteorological (MET) Instrumentation. The MET instrumentation is employed to characterize the ambient conditions. It is important to know these conditions during all tests to evaluate, as well as to estimate (or measure), the effects of the intervening atmosphere on the sensor image. The MET measurement facilities may either be provided by auxiliary technical experts (meteorologists) or dedicated (and calibrated) instrumentation employed on the range for testing. The parameters that need to be monitored are reported in Appendix A.

j. Data Processing Instrumentation. Data processing instrumentation includes image recording and instrumentation and computer processing hardware and software.

Image processing software may take many forms and it is not appropriate to specify what particular software is required. However, important tasks that should be addressed by the software include, as a minimum, capabilities to carry out image segmentation and the assignment of temperatures to image zones based on intensity levels in the image.

3. REQUIRED TEST CONDITIONS.

a. General. For any test activity there will always be a number of actions required for the preparation of the SUT, measurement equipment, and facilities prior to test commencement. A checklist of all the required activities, tailored for the specific test, should be prepared well in advance of the activity. The tester should have a copy of the Security Classification Guide for the SUT (the total system, not a component), and be aware of the possibility of correlating signature information to system vulnerability.

b. Target Preparation. The test item must be available in the condition required for appropriate testing. This means that the SUT shall be in the configuration normally employed during field use, with all components and accessories mounted and fully operational. It must be painted and prepared as required for combat, and be tested free of mud, dust, etc.

c. Range Preparation.

(1) Given that the target configuration may be classified, all proper security precautions, including access control and target storage, should be in place well before test initiation.

(2) For testing requiring the use of tower elevation for the sensor mounting and turntable operation for target rotation, the appropriate mechanical and electrical equipment must be fully operational and configured.

d. Instrumentation Preparation. Preparation of test instrumentation primarily means ensuring that all critical pieces of equipment are properly calibrated. This includes the IR sensors, blackbody reference sources, and MET sensors and target instrumentation.

e. Test Scheduling. The test period must be scheduled in accordance with the suitable availability of all the key components. This includes:

(1) Time to prepare all aspects of the target, range, and instrumentation.

(2) Range and facilities availability.

(3) Availability of all required test personnel.

(4) SUT availability.

(5) All required instrumentation calibrated and available.

(6) Suitable availability of resources required for data analysis and post test processing.

4. TEST PROCEDURES.

In general, for full acquisition of SUTs MWIR and LWIR signature data, two main test types are required: static and dynamic. The static test is conducted under two kinds of conditions: with the vehicle cold and with the vehicle idling (operational). The dynamic test is conducted with the vehicle moving. Both static and dynamic testing are conducted under various conditions of solar loading and for various viewing aspects of the target image.

4.1 Test Planning.

Plan each SUT IR measurement project based on the following considerations:

a. Main Systems. Exhaust outlets and grilles (to include vehicle exhaust if requested), radiators, tires, suspension systems, heating systems, nuclear, biological, chemical (NBC) systems, and exposed metal surfaces (especially where warmed by engine heat through operation or by solar heating) emit IR radiation and permit detection of the SUT by sensor directed weapons or surveillance systems. IR measurements are collected of SUTs to assess their detectability and to identify temperature variations (ΔT) that could make the vehicle vulnerable

to land and airborne heat-seeking weapons. Consideration can then be given to shielding the hot spots or redesigning to suppress the IR radiation.

b. Auxiliary Systems. Personnel heaters or on-board auxiliary generators create signatures and are considered to be IR sources in addition to the basic SUT. Personnel heaters should not be used during IR signature tests, unless directed otherwise.

c. Deployment. The final deployment scenario of a SUT should be considered when conducting a test. For example, an NBC decontamination unit would generally NOT be deployed to the front line. Thus, this item may not be required to suppress close range signature emissions.

d. Operational Scenario. The operational requirements of the SUT vehicle are required to determine the level of spatial and temperature resolution needed and the test procedures to use. For example, the SUT may be in defilade 20 percent of the deployment time, or the system may be in an inactive state for 30 percent of the time.

e. Orientation of Meteorological Station.

(1) Care should be taken in establishing the location and orientation of the MET station. The MET data should experience the same solar fluctuations and environmental differences as the SUT.

(2) The solar radiation sensor must be located at the test target(s) area, in the same area as the SUT to experience the same solar loading. The solar radiation sensor must give an instantaneous (defined as approximately 5 to 10 min intervals) number of the W/m^2-steradain (sr) arriving at the test target(s) for the preceding unit of time in a known spectral range.

(3) Insolation (integrated solar radiation) should be measured from two instruments parallel to the ground. One unit is to face up (Solar Irradiance) and the other is to face down (Reflected Irradiance). These data samples should be taken at 1-minute intervals during actual data collection and 15- to 30-minute intervals at all other times. These data should be collected in total W/m^2 in a known spectral range.

4.2 Static Test Procedures.

The primary purpose of a static test is to fully quantify the SUT's thermal signature from all aspects with the vehicle cold and with the vehicle idling. The cold test is essentially a test of the effect of solar loading. It must be conducted under a representative range of solar loading conditions. This test must be conducted over a full cycle of day and night (24 hr) it can properly be characterized as a diurnal test. Thermal imagery will be collected with a calibrated MWIR and a LWIR imager.

4.2.1 Diurnal Test Procedures.

a The SUT(s) should be positioned at the test site by the late afternoon of the day before testing is to begin. Three blackbody calibration sources are placed in front of the SUT in an open field so as to appear below the target in the image. The temperatures of the blackbodies

should be adjusted so that the coolest and the hottest blackbody sources bracket the coolest and the hottest zones of the target. The temperature of the middle blackbody should be set approximately halfway between the other two. The sensors should be positioned on an elevated platform and raised to the initial depression angle.

b. At selected times (usually 1-hr intervals) over a 24-hour cycle, a calibrated digital image should be taken from a MWIR and LWIR sensor, and if possible, 2 to 3 minutes of data should be recorded on video tape or on a Digital Video Recorder (DVR) from the same imagers for each measurement. Upon completion of the diurnal test, the data should be reduced on an image processing system to evaluate the radiance and apparent temperature values for each defined zone of interest on the SUT.

c. Such measurements will usually consist of a single azimuth angle at each of a number of depression angles. Immediately after each measurement series of viewing angles, the radiance of each blackbody should be measured with a calibrated radiometer and recorded.

d. The SUT data should be acquired for each depression angle. A suitable set of depression angles would include: 0, -20, -35, -60, and -75°. The first depression angle measurement should be repeated to determine if the system has undergone any changes due to environmental influences.

e. Note that if weather conditions change drastically over the diurnal cycle (heavy rain, significant change in cloud cover) it may be necessary to repeat the test on a different day.

4.2.2 Operational (Stationary) Test Procedures.

a. The operational or idle test is conducted over a full range of azimuth and depression angles. Immediately after each measurement series of viewing angles, the radiance of each blackbody should be measured with a calibrated radiometer and recorded.

b. The IR sensor should be placed on the elevator lift and raised to achieve the required depression angle. Three blackbody calibration sources must be placed in front of the turntable so as to appear below the target in the image. The temperatures of the blackbodies must be adjusted so that the coolest and the hottest sources bracket the coolest and the hottest spots in the image. The temperature of the middle blackbody should be set approximately halfway between the other two.

c. The SUT will be fully exercised, in accordance with the standard warm up stated in Table 3 for the type of operation specified in the Test Plan, and then placed (driven) onto the turntable. The SUT engine will be set to either normal or tactical idle and any other auxiliary equipment turned on as specified in the Test Plan. A calibrated digital image should be taken from the MWIR and LWIR imager.

TABLE 3. STANDARD WARMUP

CONDITION	TYPE OF OPERATION
Static solar exposure	Expose the vehicle, not operating, to outside ambient conditions for 12 hours before test.
Standard slow idle	After standard warmup[a], position the vehicle at the test station to remain at idle (typically 600 to 700 engine revolutions per minute (rpm)) for 3 minutes before data collection.
Standard fast idle	After standard warmup[a], position vehicle (tactical idle) at test station to remain at fast idle (typically 1200 to 1500 engine rpm) for 3 minutes before data collection.
Standard slow operation	Move the vehicle steadily at 8 kilometer (km) (5 miles per hour (mph)) in low range or 1 to 2 gear.
Standard moderate-speed	Move the vehicle steadily at 16 km (10 mph) operation in high range or high gear.
Standard high-speed	Move the vehicle steadily at 32 km (20 mph) operation or three-quarters maximum red-line engine rpm.

[a]Standard warm-up: Operation of test vehicle 15 minutes over clockwise course and 15 minutes over counterclockwise course in high range or high gear at 16 to 32 km or 2000 to 2400 engine rpm. Five minutes in transit time allowed to move vehicle from starting point to warm-up area.

d. Signature measurements should be carried out on two separate SUTs, typically a baseline SUT and an improved SUT (A1). In order to ensure that the two SUTs are tested under the same environmental conditions, the SUTs must be tested one immediately after the other. The first SUT should be exercised and placed into position on the turntable. While data collection is proceeding on the first SUT, the second SUT should be exercised and placed on the turntable after data collection is completed on the first.

e. Target images should be acquired for each of eight azimuth angles in 45º increments: 0, 45, 90, 135, 180, 225, 270, and 315º. The 0º azimuth is defined as a straight-on look at the front of the SUT. The first azimuth angle measurement should be repeated to determine if the SUT has undergone any changes due to environmental influences. Each set of the azimuth angles should be acquired for various depression angles.

f. A suitable set of depression angles would include: 0, -20, -35, -60, and -75º. This full set of all viewing angles should be repeated for representative solar loading conditions. Commonly, four such daily solar conditions are considered representative. These are solar loads 0, 1, 2, and 3 defined by:

(1) Solar Load 0. The minimum load solar condition, occurring from 4.5 hours after sunset to 1.5 hours before sunrise.

(2) Solar Load 1. Early morning solar load, occurring from one to 2.5 hours after sunrise.

(3) Solar Load 2. The maximum solar load condition, occurring in mid-afternoon, characteristically between 1300 and 1500 hours under a clear sky.

(4) Solar Load 3. Evening solar load occurring from 1.5 hours before sunset to a one-half hour after sunset.

g. The full complement of these four measurement conditions for all the defined aspect angles would involve 10 to 14 hours of testing time over a 24-hour period to complete the test depending on the time of year.

h. This procedure should be repeated for all the required depression angles and solar load combinations. The data can then be reduced on an image processing system to evaluate the radiance and apparent temperature values for each defined vehicle zone of interest.

i. The large number of measurements required for the full matrix of viewing angles and solar load conditions will require that the testing be conducted over several days.

4.3 Dynamic (Moving) Test Procedures.

a. The dynamic test must be conducted with the SUT moving. SUT movement should be conducted on a suitable test track (Figure 2) with SUT in high gear at speeds of 10 to 20 kilometers per hour (km/hr) with an equal number of right and left turns made by the SUT in order to equally exercise both sides of the SUT suspension and drive train components.

b. The MWIR and LWIR sensors need to be placed in at least two different locations in order to acquire data for a full range of aspect angles. Refer to Figure 2 for an example of this configuration. The SUT should move at a constant speed in high range or high gear through the measurement zone. The measurement zone is defined as an area of approximately 20 feet over a secondary road. Figure 2 illustrates how this can be configured. Blackbody sources shall be positioned so that they are in the imager FOV at the required SUT aspect angles and allowed to come to equilibrium at their set temperatures. Six of the required aspects can be acquired from the broadside location alongside the track and the other two aspects (head-on and rear views) can be acquired looking down the length of the track.

c. It will typically be possible to acquire these views for only the zero depression angle. In some cases the compounding effects of dust on the SUT are required to be minimized. For these cases, it will be necessary for the test track to have an asphalt or concrete surface.

4.4 Spectral Radiant Intensity Procedures.

a. The spectral radiant intensity, an additional parameter needed for the optimal measurement of IR emission from a SUT, is generally obtained using an interferometer or a spectral radiometer covering the 2- to 12-μm wavelength region.

b. General Data Collection Method. The SUT should follow the general scenario as outlined under paragraphs 4.2 and 4.3. The exceptions are that the background data must be collected as close to the SUT data collection time as feasible. Operate the SUT in accordance

with conditions of Table 3. Collect spectral data of the background without the SUT. Then move the SUT into the scene and collect another set of spectral data. The SUT should be at a distance which just fills a significant portion of the FOV of the spectral radiometer being used to collect the measurements.

c. Temporal Data Collection Method. To obtain information about the temporal effects of a SUT, such as the warm-up or exhaust, use the measuring instrument at a single aspect of the SUT. In this instance, the SUT is NOT warmed up in accordance with Table 3, but is warmed up while being monitored. These should begin with signatures of a cold SUT and continue at intervals of 1/2 minute, 5 minutes, 30 minutes, and 2 hours after engine starts.

5. DATA REQUIRED.

This section describes the test data to be recorded. The data collection should be adequate for correlation with test data on the same or similar items obtained at different times or locations. The data to be acquired are similar for both portions of the static test as well as the dynamic test. These data consist of calibrated IR data, temperature measurements, and information on test conditions. All data collected shall be time stamped with date and local time.

5.1 Imagery Data.

a. IR signature data must be collected in both the 3- to 5-µm and 8- to 12-µm spectral regions over several SUT aspects. Each data set should be defined by the solar load, depression angle, and azimuth angle at which thermal imagery is collected. A sample for the tabular listing of all of the required conditions is found in Appendix B. The thermal data for each SUT aspect should be separated into selected zones. The SUT zones of interest are uniquely defined for each test. Both radiance (W /cm^2-Steradian (Sr)) and apparent temperature (ºC) must be calculated for each SUT zone, the entire SUT, and the background. Values calculated for radiance and temperature should include the mean, standard deviation, maximum, and minimum values encountered. Thermal imagery should also be collected on the background, without the SUT in the image to provide information for use in background clutter analysis.

b. Digital Imagery. Digital imagery should be collected and stored on a removable digital media such as DVDs or removable drive. These media should be clearly marked with the classification, date, time and instructions, if any. Each media should be uniquely identified to allow inclusion of the ID into a database for later retrieval and archiving.

5.2 Nonimagery Data.

The spectral IR signature data should be collected in the 2- to 12-µm spectral regions over several SUT aspects. Each data set should be defined by the date, time, solar load, spectral background data, depression angle, and azimuth angle at which measurement is collected. The SUT radiance (mW/cm^2-Sr) should be calculated by subtracting the background spectral radiance from the background and SUT radiance values and reported for each SUT aspect and the background. Values calculated must include the error bars and alternate sources of error with the system and measurement conditions. Spectral data should also be reported on the

background, without the SUT in the image, to provide information for use in background clutter analysis.

5.3 Supporting Data.

a. Several types of data, in addition to thermal imagery, may be collected. These include actual temperatures on the SUT exterior, meteorological data, and test documentation including still photography of the SUT and test setup.

b. An important adjunct to the imagery data is the determination of the actual temperatures on the various target zones. These may be acquired during the static testing through the use of contact sensors (thermocouples or thermistors) on the zones of interest. For such measurements, at least two sensors are to be employed for each target zone. Spectral data may also be collected using a Spectral Reflectometer.

c. Meteorological data must be collected at 1-minute intervals during the actual data collection, and every 10 minutes during the times which data are not being collected, at the test site in accordance with the parameters listed in Appendix A, Table A-2.

d. Test documentation includes the characterization of all pertinent information on data logging forms such as those found in Appendix C. In addition, still photography should be taken with a 35-mm (or equivalent) camera showing all aspects of the SUT and close-in pictures where significant detail exists. Still photographs should also be taken of the range test setup showing the relationship of the various elements of the test, including the SUT, imager, blackbody calibration sources, and scene background and foreground.

5.4 Test Controls.

To verify the accuracy of the measurement, and to eliminate systematic errors, it is a good idea to apply contact thermocouples to the vehicle. Hand-held spot radiometers can be used as well, which measure radiant energy, like the thermal imager. Still, errors will remain, as below:

a. Uncertainty Due To the Thermal Sensor Itself and the Intervening Atmosphere. The inherent uncertainty in a modern thermal imager is usually a fraction of a degree and is insignificant compared to the sampling uncertainty, described below. The atmospheric path may be important, if it is long enough, and it may both remove and add radiant energy. To compensate, blackbodies may be placed at the SUT location or at another location but at the same range as calibration sources. Blackbody temperatures should approach the coldest and the hottest extremes of the SUT and background temperatures.

b. Uncertainty Due to Sampling Error. A separate source of error is sampling error, because the combination of SUT and environment is but a single sample out of a diverse population of different SUTs in different environments, whose typical signature is the ultimate objective. For example, SUTs may differ in their paint or cleanliness, affecting their emissivity, that is, the efficiency with which they radiate energy. If a SUT has an emissivity of 85 percent, it radiates 85 percent of the energy that a perfect blackbody would at the same temperature. But it also reflects its environment, like a mirror, at complementary 15-percent efficiency. Thus the

signature of any SUT outdoors will contain an emitted component, based on its surface temperature, and a reflected component, based on its environment. The former will vary with current and recent exposure to sun, ambient air and wind, and the latter with nearby buildings or vegetation, and cloud cover, among other things. Added to this is variability in the state of its engine deck, exhaust outlet, gun tube and suspension, all of which depend on how the SUT has been recently used. Consequently any single measurement will not account for all the possible states. The US Army Night Vision and Electro-Optic Systems Directorate (NVESD) estimated some 18 million tests would be required to fully characterize a SUT signature. Even to define these SUTs and environments as narrowly as possible, and thus to minimize this error, requires instruments, such as wind meters, which themselves have inaccuracies. The more broadly these environments are defined, the greater this sampling error.

c. Uncertainty Due to Spectral Mismatch Between Imager and Tactical Sensor. If there is a spectral mismatch between the imager used to collect the signature and the tactical sensor it is intended to duplicate, the measured signature may not exactly apply. This depends on the spectral region in which the mismatch occurs, and its magnitude. Some regions, for example, are more affected by atmospheric attenuation than others, or the presence of combustion gasses. Further information on spectral mismatch errors, including examples showing potential error from spectral response mismatch between laboratory and tactical sensors, and many other topics related to signature measurement, are provided in the Range Commanders Council (RCC) Document 809-10[1]*. Copies are available from the Signature Measurements Standards Group (SMSG) of the RCC.

6. PRESENTATION OF DATA.

This section describes how the test data should be prepared for presentation. The primary data to be presented are the determinations of SUT signatures. The signature data can be expressed in terms of radiance from the target surface in units of $W/(cm^{2-}Sr)$ or as apparent temperature in units of ^{o}C.

6.1 Determination of System Under Test (SUT) Signatures.

In order to determine the radiance and apparent temperature of the defined target zones, the following measurements and processing procedures are required.

a. Pixel Intensities and Radiance. The pixel intensities in each scene are calibrated through the use of the blackbody sources in the imagery or predetermined/measured calibration files for a given thermal imaging system. The blackbody temperature is noted and the appropriate isothermal zone in the image is bounded. The mean value and standard deviation of the pixels in each such zone for each blackbody in the image is then determined through an image-processing program. The mean radiance is then calculated from Planck's equation, the known emissivity of the source, and the system characteristics of the imager (viewing geometry, relative spectral transmission, sensitivity, and gain). This procedure defines a calibration curve of radiance within the imager scene as a function of observed pixel value. The radiance values then imply an apparent object temperature with an assumed unit emissivity. Given the

*Superscript numbers correspond to Appendix E, References.

calibration curve for each image, it is then possible to determine the radiance or apparent temperature of the SUT and the background.

b. Target Zones. The thermal image for each vehicle aspect should be separated into selected SUT zones. The SUT zones of interest are uniquely defined for each test. Each zone of interest is defined in the imagery data. The image-processing program then determines the mean and standard deviation of the pixel values for each of these defined zones. The pixel values are then directly converted to radiance or apparent temperature on the basis of the image calibration. These signature values may also be computed for the entire SUT and for any portion of the background scene.

c. Background Definition. The most important measurements of the significance of the SUT signature is obtained by comparison with the surrounding background. The background should be defined as the area immediately adjacent to the SUT containing twice the area of the SUT. This background must be centered on the centroid of the SUT, but excluding the SUT measurements. Current philosophy dictates that if an area of widely different radiance is encountered in this background (such as the sky), then the background perimeter shall be reduced in size proportionately until this area is no longer in the background. However, the background size may only be reduced to a minimum of 1.67 times the SUT area.

d. Contrast Metrics. The thermal signature values of a SUT and the background can be determined using different software packages developed for that purpose. Most thermal imagers will come with software to allow the operator to outline the SUT and then the software will automatically calculate the Area Weighted Average (AWA) delta-T contrast value between the SUT and the adjacent background, 2X the area of SUT, as well as all the desired statistics about the SUT and adjacent background, pixel count, minimum and maximum temperature, standard deviation, etc. Two of the most useful metrics that are used in analysis are the AWA Delta-T (ΔT) and Root Sum Square Delta-T (RSS). The formulas for these two metrics are shown in Figure 3.

1. AWA Delta T (ΔT)

$$\Delta T = \overline{T}_{tgt} - \overline{T}_{bkg}$$

$\overline{T}_{tgt}$: average target temperature

$\overline{T}_{bkg}$: average background temperature

Note: Average temperatures and variance calculated from radiance values before converting to temperature

2. RSS Delta T

$$\Delta T_{rss} = \sqrt{\left(\overline{T}_{tgt} - \overline{T}_{bck}\right)^2 + S^2}$$

$\overline{T}_{tgt}$: average background temperature

$\overline{T}_{bkg}$: average target temperature

S^2: Variance of the target

Figure 3. Infrared contrast metrics.

6.2 Presentation of Signature Data.

Calibrated thermal imagery data can be reported in different formats: digital thermal images, tabular data, and graphical plots. The form of each of the formats is described below.

a. Imagery Data. Thermal imagery video tapes (analog or digital data) selected by the test sponsor should be copied and delivered at the completion of the data acquisition. In addition, the digital imagery data should be presented in either TIFF, ARF, SAF or other format, whichever is specified or requested by the customer. All imagery data delivered to the customer must be clearly identified as to the media from which it was extracted, to include the unique identification of the media.

b. Tabular Data. A data table should be constructed for each SUT data set and background listing both radiance and apparent temperature. A separate table should list each condition of solar loading time correlated to the SUT data sets. For each vehicle zone, the vehicle as a whole, and the background tabulated data must include the mean, standard deviation, maximum, and minimum of both radiance and temperature.

c. Graphical Data. For each solar load and depression angle in the operational test, the mean radiance and standard deviation should be graphed for each radiance zone versus azimuth angle. For the diurnal test, the mean radiance and standard deviation should be graphed for the vehicle zones versus the time of day.

d Nonimagery Data. Plots of the spectral data should be presented showing the background information and the SUT data. Any differences from what would be expected of a normal spectral emission of the SUT must be highlighted, such as the peak emissions in the 3- to 5-μm region commonly referred to as the Red and Blue spikes.

e. Supporting Data. In addition to the calibrated signature data, the following supporting data are required to completely define the test results. They are defined as part of the data to be presented and should be made available to the test sponsor:

(1) Meteorological ground truth data for each day of testing.

(2) Physical temperatures of the vehicle exterior.

(3) Graphical display of solar loading versus time of day for each day of testing.

(4) A tabulation of solar angle versus time of day at the test site latitude.

(5) A brief description of the terrain surrounding the vehicle, both foreground and background.

(6) A schematic representation of the test site to include a diagrammatic layout of all instrumentation and the SUT.

(7) A tabulation of instrumentation used to collect data with associated calibration intervals.

(8) Imagery of selected target aspects.

(This page is intentionally blank.)

APPENDIX A. FACILITIES AND METEOROLOGICAL REQUIREMENTS.

TABLE A-1. RECOMMENDED FACILITIES

ITEM	REQUIREMENT
Tower	Height requirement is instrumentation dependent: must allow the imager to accommodate target, blackbodies and the background within the FOV.
Tower platform	Must accommodate instrumentation package size, weight and power requirements. Must provide imager depression angle adjustment from 0 to 90º at the target location.
Distance for turntable	Must be sufficient to allow the entire target within the imager FOV at all depression angles noted under the tower platform.
Elevating platform or crane	Must be sufficient to allow the entire target within the imager FOV at all depression angles required.
TURNTABLE	
ITEM	REQUIREMENT
Capacity	Minimum 70 tons
Deck size	Minimum 6.7 meters
Turning rate	Minimum 30º/min
Positioning accuracy	$\pm$1 degree
Loading/unloading time	< 5 minutes
Test track	Minimum 300-meter straight-a-way
Open area	Large enough for test vehicle to fill FOV of radiometer; background as required in test requirements
Firing range	As applicable to weapon under test
Digital conversion facility	As applicable to weapon under test

APPENDIX A. FACILITIES AND METEOROLOGICAL REQUIREMENTS.

Meteorological (Ground Truth) Data. The instrumentation required for the collection of meteorological data for all portions of the tests involving thermal signature collection are listed in Table A-2.

TABLE A-2. METEOROLOGICAL INSTRUMENTATION AND PERMISSIBLE ERROR.

DEVICES FOR MEASURING	PERMISSIBLE UNCERTAINTY OF MEASUREMENT
Ambient air temperature	±0.5 ºC
Relative humidity	±5 percent and >30 percent at extremes
Barometric pressure	±1 mbars
Solar irradiance	±1 percent of W/m^2 value
Reflected irradiance	±1 percent of W/m^2 value
Cloud cover	±10 percent
Precipitation type	Rain, snow, etc.
Precipitation rate	±5 percent mm/hr reading
Soil moisture	Volumetric water content
Surface texture	(Description)
Ground cover	(Description)
Wind speed	±2 km/hr
Wind direction (0-degrees defined as North)	±10 degrees
Meteorological station site	±1 meter
Soil temperature	±1 ºC
Sun position	(Latitude and longitude)

APPENDIX B. MATRIX OF TEST MEASUREMENT CONDITIONS (EXAMPLE).

Solar Load	Sensor Depression Angles, deg	Target Aspect Angles, deg							
		0	45	90	135	180	235	270	315
SL0	0								
SL0	-20								
SL0	-35								
SL0	-60								
SL0	-75								
SL1	0								
SL1	-20								
SL1	-35								
SL1	-60								
SL1	-75								
SL2	0								
SL2	-20								
SL2	-35								
SL2	-60								
SL2	-75								
SL3	0								
SL3	-20								
SL3	-35								
SL3	-60								
SL3	-75								

Figure B-1. Example of measurement matrix for static engine operating test.

(This page is intentionally blank.)

APPENDIX C. DATA COLLECTION SHEETS.

The following data are to be recorded for each test:

Vehicle Type/Identification ________________________________
Vehicle Serial Number ________________________________
Engine Identification ________________________________
Date/Location of Manufacture ________________________________
Odometer Reading ________________________________
Surface Condition Paint ________________________________
Cleanliness ________________________________
Mechanical Condition ________________________________
Condition of Exhaust Area ________________________________
Payload, Attachments ________________________________

Checklist of Documentation
____ Photographic survey
____ Diagram with dimensions of engine compartment and exhaust area
____ Speed versus rpm table/chart

Figure C-1. SUT identification and condition.

Date _____ Time _____

Imager Type _____ Waveband _____
Test Type: _____ Diurnal _____ Operational _____ Dynamic
Solar Load Condition _____
View Depression Angle_____
Target Azimuth Angle_____
Blackbody Set Temperatures 1______ 2______ 3______
Comments/Special Conditions ______________________________

Figure C-2. Test type and conditions.

(This page is intentionally blank.)

APPENDIX D. DEFINITIONS OF ACRONYMS.

µm	micrometer
AWA	Area Weighted Average
C	Celsius
cm	centimeter
DVR	digital video recorder
FLIR	Forward Looking InfraRed (this definition generally refers to any IR sensor which is looking forward as opposed to strictly looking downward. The term has evolved to mean any IR imaging system being used in the military)
FOV	Field Of View (the FOV is commonly used, in optics, to describe the total area over which a detector system views the world at a single point in time. A more technical definition can be found in any book on optics)
GPS	Global Positioning System
IFOV	Instantaneous Field Of View (IFOV refers to the portion of the target space imaged onto an individual detector in a detector array. It has become a standard measure of performance for scanning IR imagers. Determination of IFOV only requires knowing the focal length of the optical system and the physical size of the detector element. The IFOV is usually expressed in milliradians (mrad). For MOST systems the IFOV IS NOT THE SAME AS AN IMAGE PIXEL. Thus there is no one-to-one correspondence of an IFOV to a pixel)
IR	InfraRed (an acronym commonly used in discussions of the infrared portion of the electromagnetic spectrum)
IRIG	International Range Instrumentation Group
K	Kelvin
km	kilometer
km/hr	kilometer per hour
LWIR	Longwave-InfraRed (LWIR refers to the far Infrared portion of the electromagnetic spectrum. In this document this area is nominally defined as that part of the electromagnetic region between 8- and 12-µm)
m	meter
MET	meteorological (the meteorological data are usually referred to as MET data for ease of discussion)

APPENDIX D. DEFINITIONS OF ACRONYMS.

mph	miles per hour
MRAD	milliradian (angular measurement for field-of-view)
MRT	Minimum Resolvable Temperature (The MRT (or MRTD, as it is sometimes stated) is the crucial measure of performance for an IR imaging system that provides a video display to an observer. The MRT is a function expressing the minimum temperature contrast required to resolve a thermal bar target pattern as a function of spatial frequency. Not surprisingly, the higher the spatial detail you are trying to resolve with an IR imager, the higher is the temperature contrast required. The MRT measurement is accomplished with a thermal target consisting of four bars, each with a 7 to 1 aspect ratio. The bars and their background are adjustable in apparent temperature. One measures the temperature difference between bars and background required for the average observer to just resolve the bars from the background. Sets of bars with different spatial frequency are required to evaluate a range of spatial frequencies.)
MTF	Modulation Transfer Function (The MTF is a standard measure of optical performance for imaging systems. It is probably the crucial measure of imaging quality for optics, both visible and IR (although for IR, MRTD is a more important measure for the system as a whole). The MTF essentially measures the optical system's efficiency at transmitting spatial frequency details. It is always normalized to a value of 1.0 at zero spatial frequency (any optical system can transmit no spatial detail with perfect fidelity). It falls off towards zero (no ability to transmit spatial details) at higher and higher spatial frequencies. All optical systems have zero MTF beyond a critical cutoff frequency (fc) that depends only on the optics diameter (D) and the operating wavelength (fc = D/λ). No scene details with this, or higher, frequencies can be resolved by the optical system.)
MWIR	Midwave InfraRed (MWIR refers to the mid Infrared portion of the electromagnetic spectrum. In this document this area is nominally defined as that part of the electromagnetic region between 3- and 5-μm)
NBC	nuclear, biological, chemical
NEPD	Noise Equivalent Power Density (Noise equivalent power density is a measure of a detection system's sensitivity. It can be used in reference to an IR detector or a millimeter wave system. It is usually defined as the input power level that induces a system signal level having a signal to (system) noise ratio of one. This requires a voltage measurement of the system output as a function of (a variable) input signal.)

APPENDIX D. DEFINITIONS OF ACRONYMS.

NETD	Noise Equivalent Temperature Difference (Noise equivalent temperature difference is a measure of performance for IR systems. It refers to the apparent temperature difference in the scene required to give the same signal level as the RMS background noise in the detector system itself.)
NFOV	Narrow Field of View
NVESD	US Army Night Vision and Electro-Optic Systems Directorate
R_λ	Spectral Response (also termed Responsivity) (The spectral response of a detector is used in the calibration of a thermal imager, and subsequent calculations of the temperature from radiance. The detector response in the thermal imager is linear in radiometric quantity and non-linear in temperature. This non-linearity is strongly dependent upon the spectral response. Thus, R_λ is critical to determine the exact amount of radiation received from the reference sources or from the target and to convert radiometric data to temperature.)
RCC	Range Commanders Council
RF	radio frequency
rpm	revolutions per minute
RSS	root sum square
SMSG	Signature Measurements Standards Group
sr	steradian
SUT	system under test
TOP	Test Operations Procedure
W/cm^2-sr	Watts per centimeter squared per Steradian.
WFOV	Wide Field of View (one of several video displays used in the desktop computer arena)

(This page is intentionally blank.)

APPENDIX E. REFERENCES.

1. RCC 809-10, Standards and Procedures for Application of Radiometric Sensors, July 2010.

For information only (related publications).

a. Ballistic Research Laboratories, Procedure for the Reduction of IR Scanner Data, Aberdeen Proving Ground, MD, April 1977.

b. Baumann, J.L., and M.D. Dixon, Precision Stabilization Requirements for Long-Range Acquisition Systems, SPIE Vol. 187 System Aspects of Electro-Optics, 1979.

c. Hoover, C., J. Ratches, F. Shields, and K. Mayo, Night Vision and Electro-Optics Laboratory (NVEOL) Performance Model and Its Uses, SPIE Vol. 327 Sensor Design Using Computer Tools, 1982.

d. Hudson, R.D., Infrared System Engineering, John Wiley & Sons, NY, 1969.

e. Jacobs, Pieter A., Thermal Infrared Characterization of Ground Targets and Backgrounds, 1996.

f. Sabol, B.M. and K.G. Hall, Image Metrics Approach to Understanding Effects of Terrain and Environment on Performance of Thermal Target Acquisition Systems, US Army Engineer Waterways Experiment Station, Vicksburg, MS, 1989.

g. Spiro, I.J. and M. Schlessinger, Infrared Technology Fundamentals, Marcel Dekker, Inc, NY, 1989.

h. Thermal Infrared Signature Standards, Ver. 1.0, Published by National Signatures Program (now Signatures Support program), 1 December 2007.

i. Wolfe, W. L. and G.J. Zissis, eds., The Infrared Handbook Environmental Research Institute of Michigan, Office of Naval Research, Washington, DC, 1978.

(This page is intentionally blank.)

Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Range Infrastructure Division (CSTE-TM), US Army Test and Evaluation Command, 2202 Aberdeen Boulevard, Aberdeen Proving Ground, MD 21005-5001. Technical information may be obtained from the preparing activity: Commander, US Army Aberdeen Test Center, ATTN: TEDT-AT-WFT, Aberdeen Proving Ground, MD 21005-5059. Additional copies can be requested through the following website: http://itops.dtc.army.mil/RequestForDocuments.aspx, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.